US009812242B1

(12) United States Patent
Guentert

(10) Patent No.: US 9,812,242 B1
(45) Date of Patent: Nov. 7, 2017

(54) SYSTEMS AND METHODS FOR LIQUID HEAT EXCHANGE FOR TRANSFORMERS

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 16 days.

(21) Appl. No.: **15/159,387**

(22) Filed: **May 19, 2016**

(51) **Int. Cl.**
H01F 27/10 (2006.01)
H01F 27/08 (2006.01)
H01F 27/16 (2006.01)
H05K 7/20 (2006.01)

(52) **U.S. Cl.**
CPC ***H01F 27/16*** (2013.01); ***H05K 7/20263*** (2013.01)

(58) **Field of Classification Search**
CPC H05K 7/20; H01F 27/16; H01F 27/10; H01F 27/105; H01F 27/12; H01F 27/125; H01F 27/14
USPC 336/55–61, 90, 94
See application file for complete search history.

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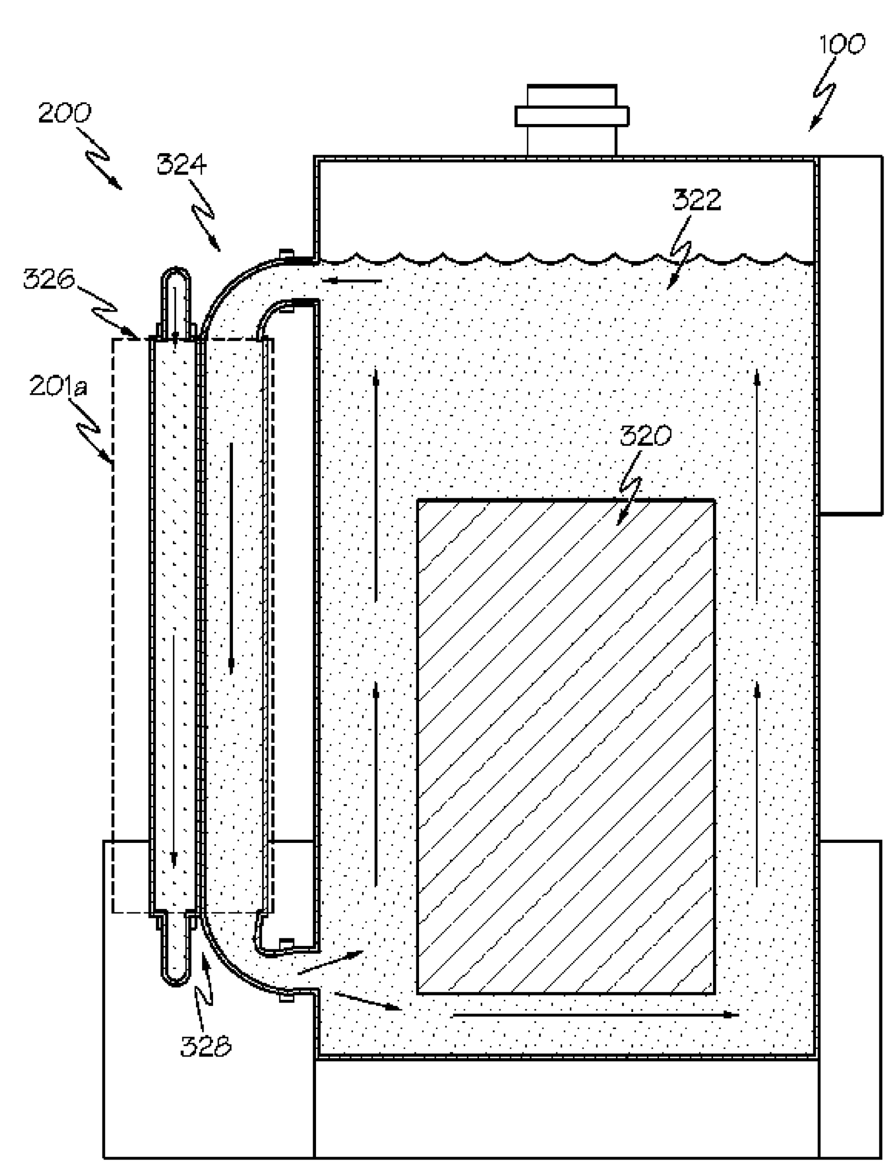
(57) **ABSTRACT**

Systems and methods for liquid heat exchange for transformers are described. One embodiment of a fluid heat exchanger includes a transformer inlet port that is coupled to a transformer chamber and receives a dielectric fluid from the transformer chamber. Also included are a cooling fluid inlet for receiving a cooling fluid and a finned heat sink that includes a fluid communicator. The fluid communicator may receive, at a first chamber, the dielectric fluid from the transformer inlet port and directs the dielectric fluid across a first plurality of cooling fins. The fluid communicator may receive, at a second chamber, the cooling fluid from the cooling fluid inlet and may direct the cooling fluid across a second plurality of fins, where the fluid communicator separates the first chamber from the second chamber with a solid divider.

20 Claims, 6 Drawing Sheets



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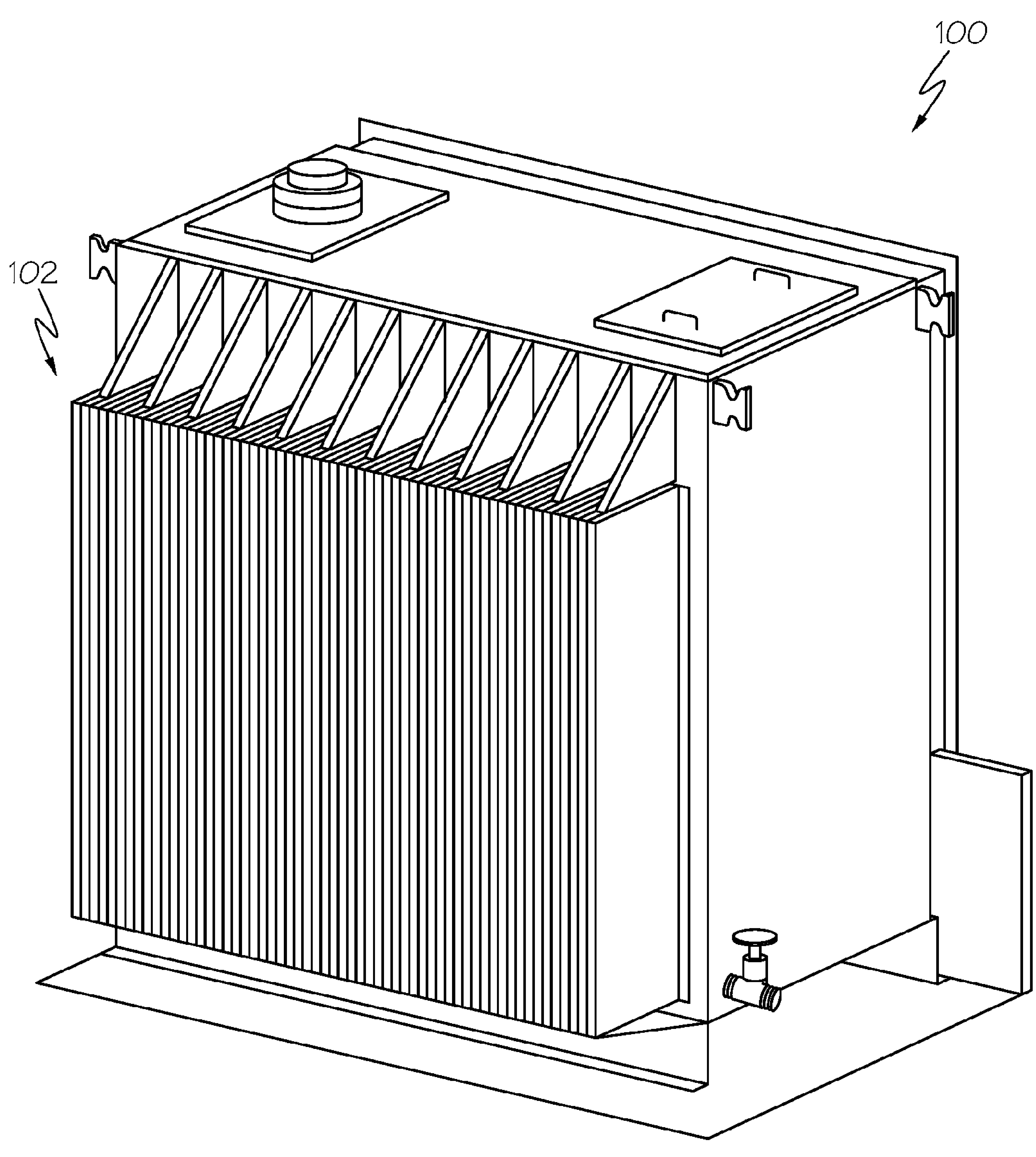

FIG. 1

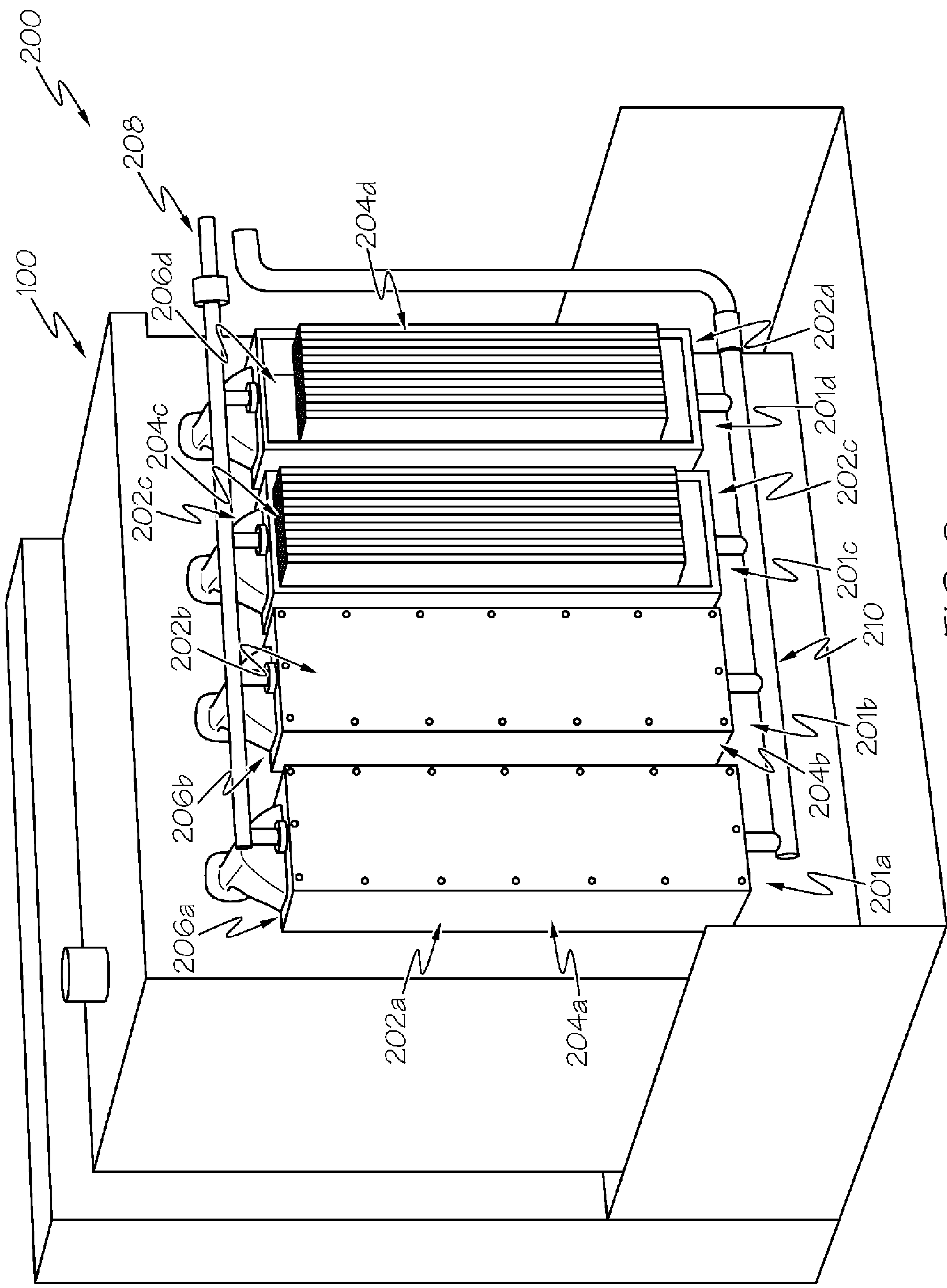
200
208
100
206d
204d
202d
201d
204c
202c
202c
201c
210
202b
201b
204b
206b
201a
206a
202a
204a

FIG. 2

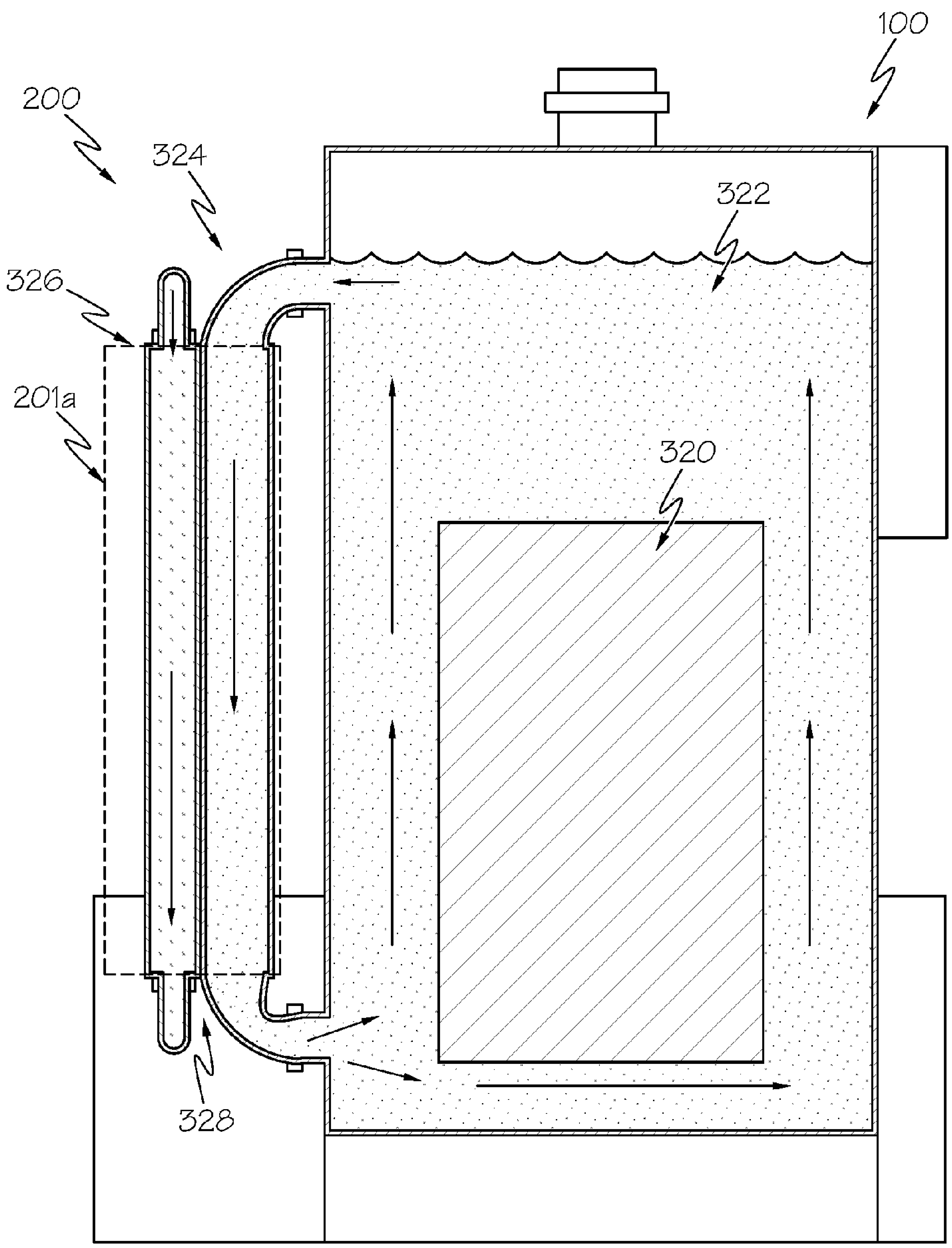

FIG. 3

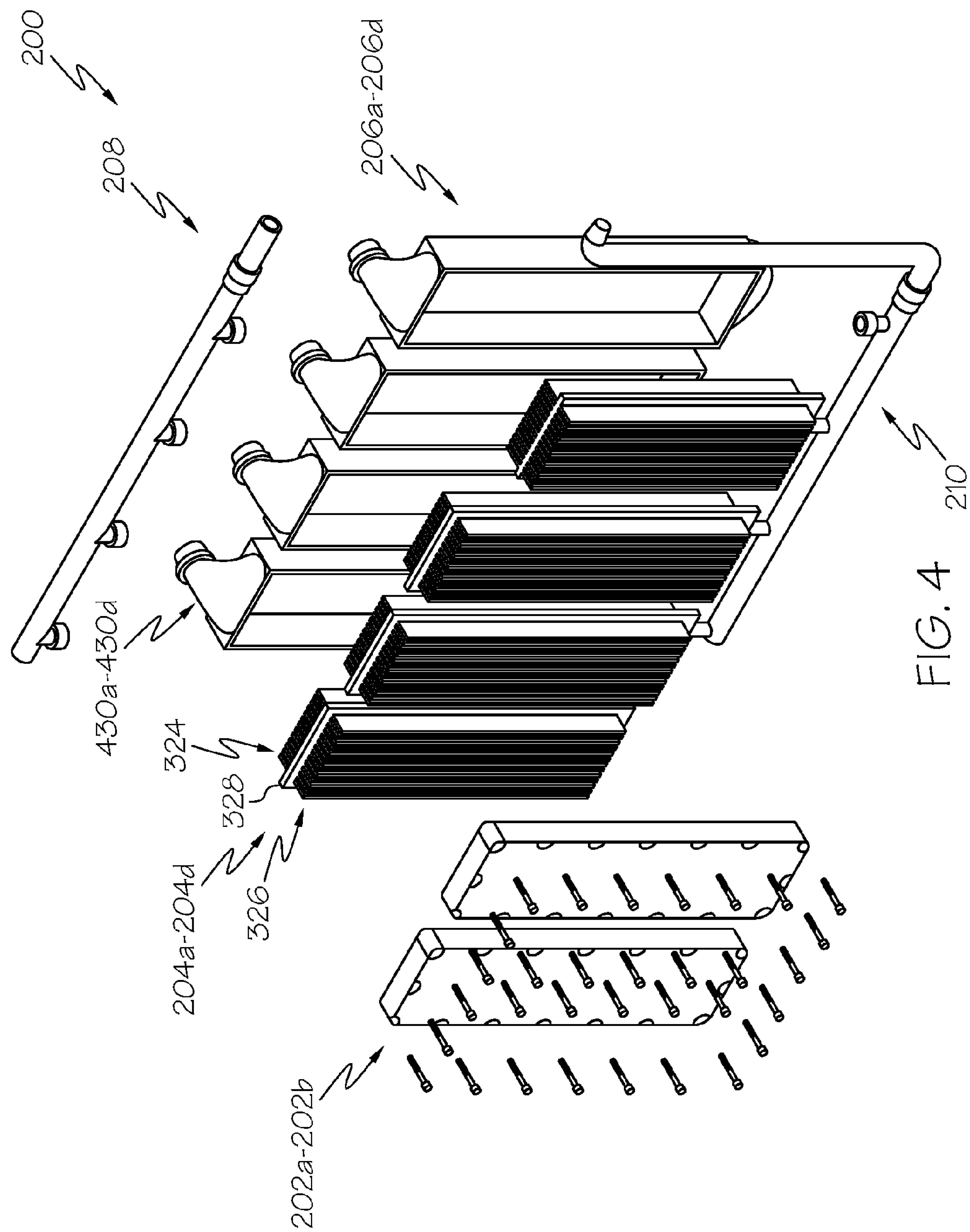
200
208
206a-206d
210
430a-430d
324
328
326
204a-204d
202a-202b

FIG. 4

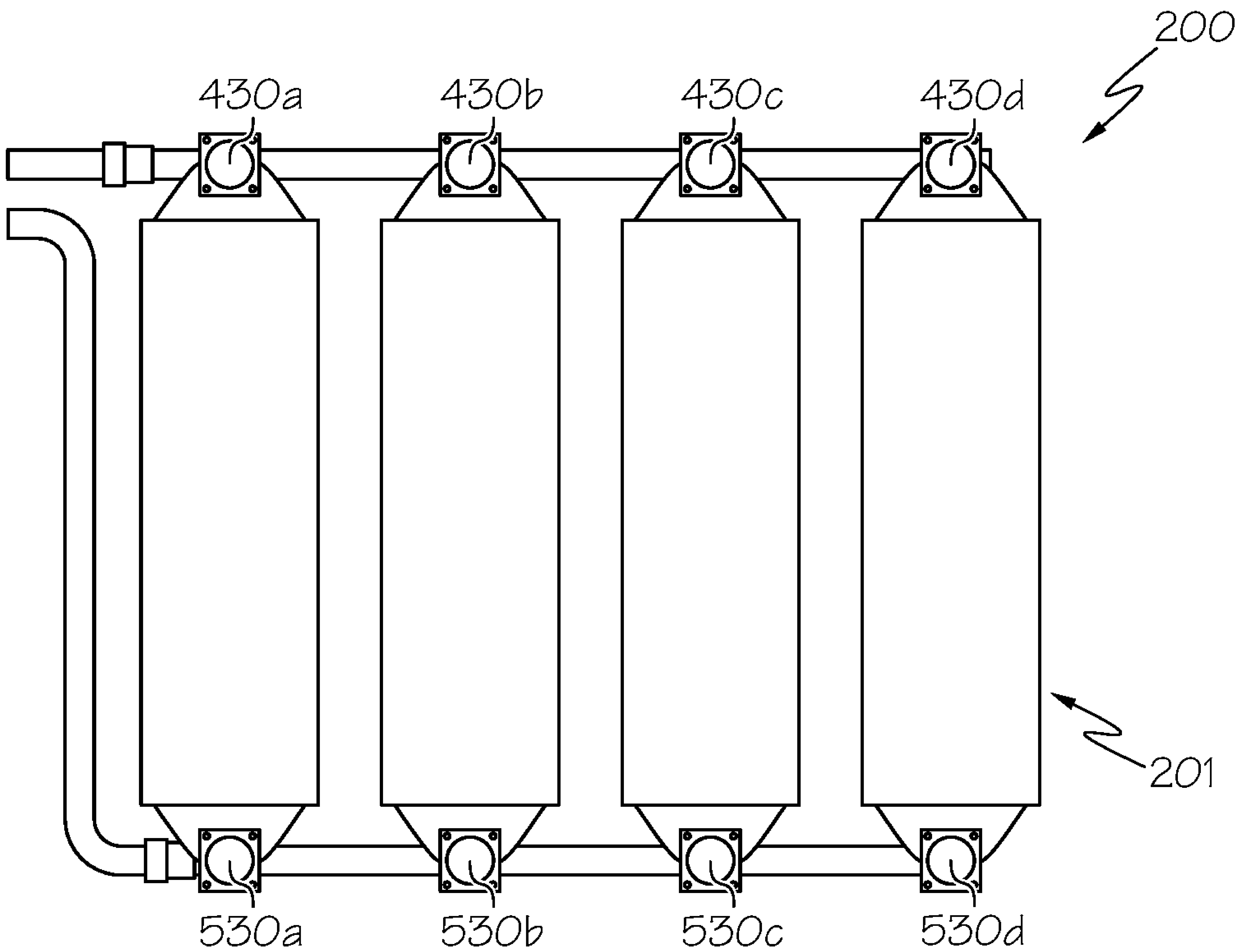
200
430a
430b
430c
430d
201
530a
530b
530c
530d

FIG. 5A

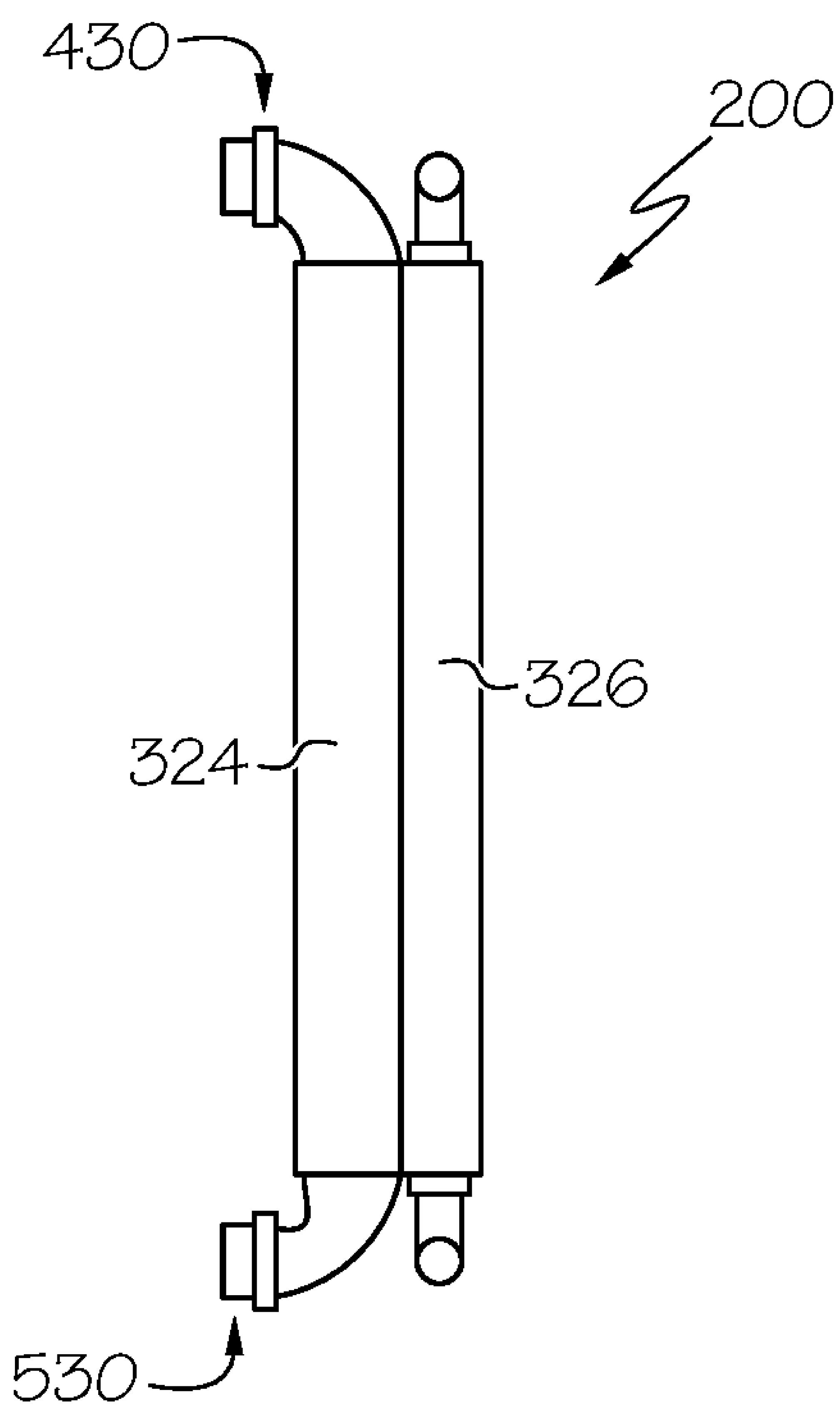
430
200
326
324
530

FIG. 5B

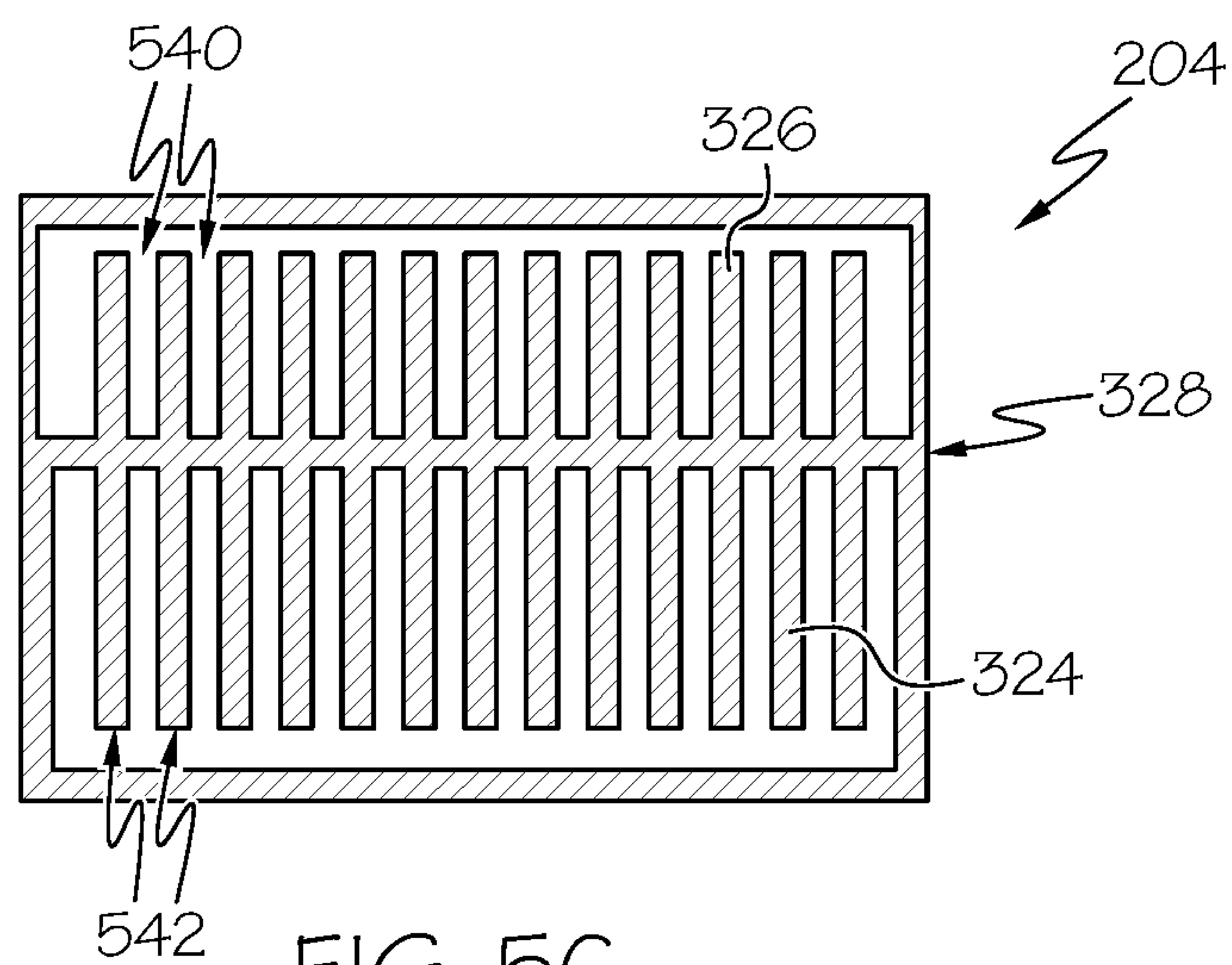

FIG. 5C

SYSTEMS AND METHODS FOR LIQUID HEAT EXCHANGE FOR TRANSFORMERS

TECHNICAL FIELD

Embodiments described herein generally relate to systems and methods for liquid heat exchange for transformers and, more specifically, to embodiments for utilizing liquid-to-liquid heat transfer.

BACKGROUND

As background, traditional liquid-filled transformers utilize large radiator banks with many hollow fins manifolded to the transformer's internal liquid, which serves to cool the internal liquid of the transformer via natural convection of ambient air over the fins. In some cases, additional cooling is achieved by forced convection. As the industry demands physically smaller transformers with increased power capacity, it is often necessary to drive additional cooling effectiveness beyond forced-convection of air. Such technological advancement will provide major advantages to industry by delivering smaller, more efficient, higher-capacity transformers ultimately reducing cost to both manufacturers and purchasers, a need exists for more efficient cooling.

SUMMARY

Systems and methods for liquid heat exchange for transformers are described. One embodiment of a fluid heat exchanger includes a transformer inlet port that is coupled to a transformer chamber and receives a dielectric fluid from the transformer chamber. Also included are a cooling fluid inlet for receiving a cooling fluid and a finned heat sink that includes a fluid communicator. The fluid communicator may receive, at a first chamber, the dielectric fluid from the transformer inlet port and directs the dielectric fluid across a first plurality of cooling fins. The fluid communicator may receive, at a second chamber, the cooling fluid from the cooling fluid inlet and may direct the cooling fluid across a second plurality of fins, where the fluid communicator separates the first chamber from the second chamber with a solid divider.

In another embodiment, a method includes receiving a dielectric fluid from a transformer, where the dielectric fluid has an elevated temperature, receiving a cooling fluid, and directing the dielectric fluid across a first plurality of cooling fins in a first chamber. Some embodiments include directing the cooling fluid across a second plurality of cooling fins in a second chamber, where the first chamber and the second chamber are coupled via a solid divider, and where the solid divider is configured as a thermal conductor to communicate heat from the dielectric fluid to the cooling fluid. In some embodiments the solid divider prevents the dielectric fluid from physically contacting the cooling fluid. Some embodiments include returning the dielectric fluid to the transformer and disposing the cooling fluid after receiving heat from the dielectric fluid.

In yet another embodiment, a system includes a transformer that generates heat, where the transformer includes a transformer chamber for circulating a dielectric fluid and a fluid heat exchanger that is coupled to the transformer. The fluid heat exchanger may include a first transformer inlet port that is coupled to the transformer chamber and receives the dielectric fluid from the transformer chamber, where the dielectric fluid is received at an elevated temperature. The fluid heat exchanger may also include a cooling fluid inlet,

for receiving a cooling fluid, a first finned heat sink that includes a first fluid communicator. The first finned heat sink may receive, at a first chamber, the dielectric fluid from the first transformer inlet port and directs the dielectric fluid across a first plurality of cooling fins. The first finned heat sink may receive, at a second chamber, the cooling fluid from the cooling fluid inlet and may direct the cooling fluid across a second plurality of fins. The first finned heat sink may separate the first chamber from the second chamber with a first solid divider that is thermally conductive such that heat from the dielectric fluid is communicated to the cooling fluid. The system may also include a cooling fluid return that disposes the cooling fluid after receiving heat from the dielectric fluid a first transformer outlet port that returns the dielectric fluid to the transformer chamber after communicating heat to the cooling fluid.

These and additional features provided by the embodiments of the present disclosure will be more fully understood in view of the following detailed description, in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments set forth in the drawings are illustrative and exemplary in nature and not intended to limit the disclosure. The following detailed description of the illustrative embodiments can be understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

FIG. **1** depicts a transformer according to embodiments described herein;

FIG. **2** depicts a transformer with a fluid heat exchanger, according to embodiments described herein;

FIG. **3** depicts a side view of a fluid heat exchanger, according to embodiments described herein;

FIG. **4** depicts an exploded view of a fluid heat exchanger, according to embodiments described herein; and

FIGS. **5**A-**5**C depict individual parts of a fluid heat exchanger, according to embodiments described herein.

DETAILED DESCRIPTION

Embodiments disclosed herein include systems and methods for a fluid heat exchanger. Some embodiments may be designed to interface with the transformer's existing bolt-on radiator bank interfaces. Accordingly, embodiments described herein pass heat from dielectric fluid, across a finned-aluminum heat sink, and into cooling fluid. As these embodiments may be utilized indoors for data centers, the cooling fluid source may be the building's chilled water supply, which is readily available throughout data centers because it is used to cool computer rooms as well as electrical rooms, where the transformers are typically located.

As described in more detail below, the dielectric fluid may circulate from the transformer chamber to a transformer inlet port. A cooling fluid loop (open loop and/or closed loop, depending on the embodiment) is circulated adjacent to the dielectric fluid, and circulates cooling fluid, such as water, saline, etc. A heat sink (which may be constructed of aluminum or other thermal conductor) may be disposed between the cooling fluid and dielectric fluid. The systems and methods for a liquid cooling or fluid heat exchanger incorporating the same will be described in more detail, below.

Referring now to the drawings, FIG. **1** depicts a transformer **100** according to embodiments described herein. As illustrated, the transformer **100** may be configured for converting electrical power from a first voltage into a second voltage. As discussed above, the transformer **100** may be configured as an indoor transformer that operates between about 750 kilo-Volt-Ampere (kVA) and about 9000 kVA. Some embodiments of the transformer **100** may be configured as an indoor-liquid transformer designed for indoor use in a data center. Specifically, the liquid insulator may include FR3 or other dielectric fluid. Accordingly, while previous solutions utilize one or more radiator banks **102** that extend outward from a back of the transformer **100**, embodiments of the transformer **100** may include a liquid cooling mechanism for providing cooling of the transformer **100**.

FIG. **2** depicts a transformer **100** with a liquid cooling heat exchanger, such as heat exchanger **200**, according to embodiments described herein. As illustrated, the heat exchanger **200** may be coupled and/or closely coupled to a surface of the transformer **100** to provide access to the dielectric fluid that is stored inside the transformer **100**. Due to the space constraints, embodiments described herein may be closely coupled such that the heat exchanger **200** is disposed within about 24 inches or less of the transformer **100**; in some embodiments within about 12 inches or less of the transformer **100**, and in some embodiments within about 6 inches or less of the transformer **100**.

The heat exchanger **200** may include a first finned heat sink **201***a*, a second finned heat sink **201***b*, a third finned heat sink **201***c*, and a fourth finned heat sink **201***d* (referred to collectively as "the finned heat sinks **201**") which each includes a first cooling fluid casing **202***a*, a second cooling fluid casing **202***b*, a third cooling fluid casing **202***c*, and a fourth cooling fluid casing **202***d* (referred to collectively as "the cooling fluid casings **202**") that enclose a first fluid communicator **204***a* (not explicitly shown in FIG. **2**), a second fluid communicator **204***b* (also not explicitly shown in FIG. **2**), a third fluid communicator **204***c*, and a fourth fluid communicator **204***d* respectively (referred to herein as "the fluid communicators **204**") that each include a plurality of cooling fins and define a first chamber, a second chamber, a third chamber, and a fourth chamber respectively. Also included are a first dielectric fluid casing **206***a*, a second dielectric fluid casing **206***b*, a third dielectric fluid casing **206***c*, and a fourth dielectric fluid casing **206***d* (referred to collectively as "the dielectric fluid casings **206**"), which are also utilized to enclose the finned heat sinks **201**.

Also depicted in FIG. **2** are a cooling fluid inlet **208** and a cooling fluid return **210**. As described in more detail below, the cooling fluid inlet **208** may receive water, saline, and/or other cooling fluid. The cooling fluid may be distributed through the fluid communicators **204**. The cooling fluid may receive heat from the dielectric fluid (which is not in physical contact with the cooling fluid, but separated by a thermal conductor within the finned heat sinks **201**). As such, when the dielectric fluid is received from the transformer chamber, the dielectric fluid may have an elevated temperature (relative to the temperature of the cooling fluid) and thus may include a predetermined amount of heat. The cooling fluid may then cycle to the cooling fluid return **210** and disposed (such as in an open loop) or cooled and recirculated (such as in a closed loop).

FIG. **3** depicts a side view of a heat exchanger **200**, according to embodiments described herein. As illustrated, the transformer **100** includes a transformer coil **320** that generates heat based on the voltage conversion. The heat is transferred to the dielectric fluid in an internal transformer chamber **322**. The heated dielectric fluid is communicated from the internal transformer chamber **322** to a transformer side **324** of the finned heat sinks **201**, which defines a first chamber. As described above, cooling fluid may be communicated to a heat exchanger side of the finned heat sinks **201** via the heat exchanger side **326** of the finned heat sinks **201**. As also illustrated, a solid divider **328** is disposed between the heat exchanger side **326** (which defines a second chamber) and the transformer side **324** of the finned heat sinks **201**. It should be understood that **328** a first solid divider may be utilized for the first finned heat sink **201***a* and a second solid divider may be utilized for the second finned heat sink **201***b*. Solid dividers may be provided for the remaining finned heat sinks **201**.

Regardless, the solid divider **328** may be constructed of aluminum, copper, brass, carbon nanotubes, iron, and/or other thermally conductive material that communicates heat from the transformer **100** to the cooling fluid, while preventing cooling fluid from physically contacting the dielectric fluid. It should be understood that a third chamber and fourth chamber may be defined by the second finned heat sink **201***b*. Other chambers may be provided by the remaining finned heat sinks **201***c*, **201***d*.

It should be understood that while many embodiments do not utilize a motor, some embodiments may include a motor (such as a first motor), pump, and/or other mechanism for directing the dielectric fluid into the heat exchanger **200**. As such, the dielectric fluid may be directed at a flow rate (such as a first flow rate). In some embodiments, this mechanism may provide a substantially constant flow of dielectric fluid to the heat exchanger **200**. Some embodiments however, may include a thermostat (such as a first thermostat) to vary the flow of dielectric fluid, based on the temperature of the dielectric fluid. Similarly, the cooling fluid in the heat exchanger side **326** may be directed (at a second flow rate) through the force provided by the cooling fluid source and/or via a motor (such as a second motor), pump, and/or other mechanism to control flow of the cooling fluid. Again, this second flow rate may be substantially constant and/or may vary based on a temperature of the transformer **100**, the cooling fluid, and/or the dielectric fluid, such as via a second thermostat.

FIG. **4** depicts an exploded view of a heat exchanger **200**, according to embodiments described herein. As illustrated, the dielectric chamber casings **206** may include a first transformer inlet port **430***a*, a second transformer inlet port **430***b*, a third transformer inlet port **430***c*, and a fourth transformer inlet port **430***d* (referred to collectively as the transformer inlet ports **430**) for receiving the dielectric fluid in the transformer side **324**. The dielectric fluid is communicated across the cooling fins of the fluid communicators **204**, which collects heat for communicating to the cooling fluid. Similarly, the cooling fluid is provided by the cooling fluid inlet **208** and communicated to the heat exchanger side **326** of the fluid communicators **204**. The cooling fluid then flows across the cooling fins on the heat exchanger side **326** to be removed by the cooling fluid return **210**. Also illustrated is the solid divider **328**, which creates two separate chambers in the fluid communicators **204**; a first chamber between the solid divider **328** and the dielectric chamber casings **206** and a second chamber between the solid divider **328** and the cooling fluid chamber casings **202**. The dielectric fluid is contained in the first chamber and the cooling fluid is contained in the second chamber.

FIGS. **5A**-**5C** depict individual parts of a heat exchanger **200**, according to embodiments described herein. As illustrated, FIG. **5A** depicts the transformer inlet ports **430**, as well as a first transformer outlet port **530***a*, a second transformer outlet port **530***b*, a third transformer outlet port **530***c*, and a fourth transformer outlet port **530***d* (referred to herein collectively as the transformer outlet ports **530**) for the finned heat sinks **201** respectively. The finned heat sinks **201** dispense the dielectric fluid back into the transformer **100** via the transformer outlet ports **530**. As discussed above, the dielectric fluid may be provided to the heat exchanger **200** via a motor or other mechanism. Similarly, some embodiment may be configured to vary the flow of dielectric fluid for each of the finned heat sinks **201**. As an example, if the first finned heat sink **201***a* is experiencing a higher temperature of dielectric fluid, the flow of dielectric fluid and/or cooling fluid may be increased relative to the finned heat sinks **201***b*-**201***c*.

FIG. **5**B further illustrates the connection between the transformer side **324** and heat exchanger side **326** of the heat exchanger **200**. Also illustrated is a side view of the transformer inlet ports **430** and the transformer outlet ports **530**.

FIG. **5**C depicts one of the fluid communicators **204** in greater detail. Specifically, the transformer side **324** may define the first chamber and may utilize free convection (or other mechanism) to direct the dielectric fluid across a first plurality of cooling fins **540** of the fluid communicators **204**. Similarly, the heat exchanger side **326** may define a second chamber and may receive the cooling fluid as described above. The cooling fluid is directed across a second plurality of cooling fins **542** in the fluid communicators **204** via forced convection or other mechanism. As described above, the solid divider **328** prevents physical contact between the cooling fluid and the dielectric fluid while allowing heat to transfer from the dielectric fluid to the cooling fluid.

As will be understood, the fluid communicators **204** may include separate compartments that prevent escape of the respective fluid. Similarly, some embodiments may be configured such that the fluid communicators **204** only create the distinct chambers when coupled with the cooling fluid chamber casings **202** and the plurality of dielectric chamber casings **206**.

As illustrated above, various embodiments for a liquid heat exchanger are disclosed. These embodiments may allow cooling of a transformer that is utilized in an indoor environment, while reducing a footprint of the overall system. This allows for greater transformer performance in a small area.

While particular embodiments and aspects of the present disclosure have been illustrated and described herein, various other changes and modifications can be made without departing from the spirit and scope of the disclosure. Moreover, although various aspects have been described herein, such aspects need not be utilized in combination. Accordingly, it is therefore intended that the appended claims cover all such changes and modifications that are within the scope of the embodiments shown and described herein.

It should now be understood that embodiments disclosed herein includes systems and methods for liquid heat exchange for transformers. It should also be understood that these embodiments are merely exemplary and are not intended to limit the scope of this disclosure.

What is claimed is:

1. A method for liquid heat exchange for transformers comprising:
- receiving a dielectric fluid from a transformer, wherein the dielectric fluid has an elevated temperature;
- receiving a cooling fluid;
- directing the dielectric fluid across a first plurality of cooling fins in a first chamber;
- directing the cooling fluid across a second plurality of cooling fins in a second chamber, wherein the first chamber and the second chamber are coupled via a solid divider, wherein the solid divider is configured as a thermal conductor to communicate heat from the dielectric fluid to the cooling fluid, and wherein the solid divider prevents the dielectric fluid from physically contacting the cooling fluid;
- returning the dielectric fluid to the transformer; and
- disposing the cooling fluid after receiving heat from the dielectric fluid.

2. The method of claim **1**, further comprising controlling a flow rate of the dielectric fluid across the first plurality of cooling fins.

3. The method of claim **2**, wherein the flow rate is variable, based on at least one of the following: a temperature of the dielectric fluid and a temperature of the cooling fluid.

4. The method of claim **1**, further comprising recirculating the cooling fluid across the second plurality of cooling fins.

5. The method of claim **1**, further comprising:
- directing the dielectric fluid across a third plurality of cooling fins; and
- directing the cooling fluid across a fourth plurality of cooling fins, wherein the third plurality of cooling fins and the fourth plurality of cooling fins are different than the first plurality of cooling fins and the second plurality of cooling fins.

6. A system for liquid heat exchange for transformers comprising:
- a transformer that generates heat, wherein the transformer includes a transformer chamber for circulating a dielectric fluid; and
- a fluid heat exchanger that is closely coupled to the transformer, wherein the fluid heat exchanger comprises:
  - a first transformer inlet port that is coupled to the transformer chamber and receives the dielectric fluid from the transformer chamber, wherein the dielectric fluid is received at an elevated temperature;
  - a cooling fluid inlet, for receiving a cooling fluid;
  - a first finned heat sink that includes a first fluid communicator that receives, at a first chamber, the dielectric fluid from the first transformer inlet port and directs the dielectric fluid across a first plurality of cooling fins, wherein the first finned heat sink receives, at a second chamber, the cooling fluid from the cooling fluid inlet and directs the cooling fluid across a second plurality of fins, wherein the first finned heat sink separates the first chamber from the second chamber with a first solid divider that is thermally conductive such that heat from the dielectric fluid is communicated to the cooling fluid;
  - a cooling fluid return that disposes the cooling fluid after receiving heat from the dielectric fluid; and
  - a first transformer outlet port that returns the dielectric fluid to the transformer chamber after communicating heat to the cooling fluid.

7. The system of claim **6**, further comprising a first motor, wherein flow of the cooling fluid through the fluid heat exchanger is controlled by the first motor that operates in response to communication from a first thermostat.

8. The system of claim **7**, further comprising a second motor, wherein flow of the dielectric fluid through the fluid heat exchanger is controlled by the second motor that operates in response to communication from a second thermostat.

9. The system of claim **6**, wherein the first finned heat sink further comprises a dielectric fluid casing and a cooling fluid casing for surrounding the first fluid communicator.

10. The system of claim **6**, wherein the cooling fluid inlet and the cooling fluid return define at least one of the following: a closed loop and an open loop.

11. The system of claim **6**, wherein the fluid heat exchanger further comprises:

a second transformer inlet port that is coupled to the transformer chamber and receives the dielectric fluid from the transformer chamber;

a second finned heat sink that includes a third fluid communicator that receives, at a third chamber, the dielectric fluid from the second transformer inlet port and directs the dielectric fluid across a third plurality of cooling fins, wherein the second finned heat sink receives, at a fourth chamber, the cooling fluid from the cooling fluid inlet and directs the cooling fluid across a fourth plurality of fins, wherein the second finned heat sink separates the third chamber from the fourth chamber with a second solid divider that is thermally conductive such that heat from the dielectric fluid is communicated to the cooling fluid; and

a second transformer outlet port that returns the dielectric fluid to the transformer chamber after communicating heat to the cooling fluid.

12. The system of claim **11**, wherein the cooling fluid inlet and the cooling fluid return are coupled to both the first finned heat sink and the second finned heat sink.

13. The system of claim **11**, wherein the dielectric fluid is directed through the first finned heat sink at a first flow rate and wherein the dielectric fluid is directed through the second finned heat sink at a second flow rate.

14. A fluid heat exchanger for liquid heat exchange for transformers comprising:

a first transformer inlet port that is coupled to a transformer chamber and receives a dielectric fluid from the transformer chamber, wherein the dielectric fluid is received at an elevated temperature;

a cooling fluid inlet, for receiving a cooling fluid;

a first finned heat sink that includes a first fluid communicator that receives, at a first chamber, the dielectric fluid from the first transformer inlet port and directs the dielectric fluid across a first plurality of cooling fins, wherein the first fluid communicator receives, at a second chamber, the cooling fluid from the cooling fluid inlet and directs the cooling fluid across a second plurality of fins, wherein the first fluid communicator separates the first chamber from the second chamber with a first solid divider that is thermally conductive such that heat from the dielectric fluid is communicated to the cooling fluid;

a cooling fluid return that disposes the cooling fluid after receiving heat from the dielectric fluid; and

a first transformer outlet port that returns the dielectric fluid to the transformer chamber after communicating heat to the cooling fluid.

15. The fluid heat exchanger of claim **14**, further comprising:

a second transformer inlet port that is coupled to the transformer chamber and receives the dielectric fluid from the transformer chamber;

a second finned heat sink that includes a third fluid communicator that receives, at a third chamber, the dielectric fluid from the second transformer inlet port and directs the dielectric fluid across a third plurality of cooling fins, wherein the second finned heat sink receives, at a fourth chamber, the cooling fluid from the cooling fluid inlet and directs the cooling fluid across a fourth plurality of fins, wherein the second finned heat sink separates the third chamber from the fourth chamber with a second solid divider that is thermally conductive such that heat from the dielectric fluid is communicated to the cooling fluid; and

a second transformer outlet port that returns the dielectric fluid to the transformer chamber after communicating heat to the cooling fluid.

16. The fluid heat exchanger of claim **15**, wherein the dielectric fluid is directed through the first finned heat sink at a first flow rate and wherein the dielectric fluid is directed through the second finned heat sink at a second flow rate.

17. The fluid heat exchanger of claim **14**, further comprising a first motor, wherein flow of the cooling fluid through the fluid heat exchanger is controlled by the first motor that operates in response to communication from a thermostat.

18. The fluid heat exchanger of claim **16**, further comprising a second motor, wherein flow of the dielectric fluid through the fluid heat exchanger is controlled by the second motor that operates in response to communication from a thermostat.

19. The fluid heat exchanger of claim **14**, wherein the cooling fluid inlet and the cooling fluid return define at least one of the following: a closed loop and an open loop.

20. The fluid heat exchanger of claim **14**, wherein the cooling fluid includes at least one of the following: water and saline.

* * * * *